

IMPACTS OF BURNING SEVERITY ON A SOUTHERN APPALACHIAN SITE¹

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Abstract—This study was designed to evaluate and compare the short- and long-term effects of high- and low- severity burns to site quality. The study area was commercially clearcut and treated using the fell-and-burn technique. Treatments of high- and low-severity burns were replicated four times in a completely random design. Rainfall runoff, sediment production, and nutrient concentration were measured after every rainfall event for one year after burning. Biomass production, planted pine survival, and hardwood sprouts were measured after one growing season. High-severity burns exposed mineral soil, increased sediment production, and decreased total biomass, but significantly increased the survival of planted pines. Low-severity burns had minimal erosion and greater total biomass, but decreased pine survival. This decrease probably results from a lack of competition control.

INTRODUCTION

Scientists have long been concerned about fire's effects on soil (Arend 1941, Wells and others 1979), and some have studied erosion, site productivity, and water quality following fires on steep terrain (Van Lear and Kapeluck 1989). However, little quantitative information is available on the effects of high-severity burning after timber harvest on variables such as runoff, sedimentation, and net primary productivity (Robichaud and Waldrop 1994). Fire severity refers to the condition of the forest floor after burning (Wells and others 1979), and burning effects range from minimal consumption of the litter layer (low-severity) to total consumption of duff and litter layers and exposure of mineral soil (high-severity) (Phillips and Abercrombie 1987, Wells and others 1979).

On the Andrew Pickens Ranger District of the Sumter National Forest, site preparation burns are often used to regenerate low-quality hardwood stands to pine-hardwood mixtures. The fell-and-burn technique (Abercrombie and Sims 1986) where residuals are felled in the spring followed by burning in the summer has been used successfully. This technique creates productive pine-hardwood mixtures with high pine survival rates and improved hardwood quality (Phillips and Abercrombie 1987). However, in two studies of the fell-and-burn technique, high-severity fires created excessive erosion that may have reduced long-term site productivity (Van Lear and Kapeluck 1989, Evans and others 1992). These studies identified a need for site-specific burning prescriptions that protect the forest floor, thereby protecting the mineral soil.

In this study, low- and high-severity burns were conducted to evaluate and compare short- and long-term effects of the two treatments. Runoff, sediment loss, site productivity, plant nutrient content, and stand development were measured for both treatments. This paper discusses short-term effects one year after treatment.

METHODS

The study was conducted on steep terrain on the Andrew Pickens Ranger District of the Sumter National Forest in northwestern South Carolina. Slopes within the study area, of 14 hectares, range from 24 to 39 percent with a southern aspect. The predominant soil type is the Cowee series, a fine, loamy, oxidic, mesic Typic Hapludult formed in residuum from weathered granite, gneiss, and schists.

The study area was commercially clearcut during the winter of 1990-1991. The major overstory hardwoods included: scarlet (*Quercus coccinea* Muenchh.), northern red (*Q. falcata* Michx.), black (*Q. velutina* Lam.), white (*Q. alba* L.), chestnut (*Q. prinus* L.), and post oaks (*Q. stellata* Wangenh.). The predominant overstory pine species was shortleaf pine (*Pinus echinata* Mill.). Understory and midstory hardwoods included red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* L.), persimmon (*Diospyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). Residual stems greater than 1.5 meters tall were felled in May and June 1991 for both burn treatments.

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Table 1—Fuel and weather conditions at time of ignition and selected fire behavior patterns for low- and high-severity burns

Measurement	Low severity	High severity
Date	June 5	July 15
Relative humidity	48%	55%
Wind	SE 5-11 kph	SE 8-11 kph
Fuel moisture sticks	11%	8%
Ambient temperature	18 deg C	30 deg C
Firing technique	Strip headfire	Strip headfire
Flame height	1-3 m	2-6 m
Fireline intensity	215-2,945 kw/m	655-13,295 kw/m
Time	1100 - 1300	1500 - 1730
Litter moisture	65.2%	5.9%
Duff moisture	98.2%	36.9%
Soil moisture	35.7%	24.5%
Rain	6 days before-37mm	12 days before-44mm

On June 5, 1991, six days after a 37 mm rainfall event, low-severity burns were applied to four 0.4 ha treatment plots (replicates). High severity burns were applied to another four plots on July 15, 1991, twelve days after a 44 mm rainfall event. Low-severity burns were of high-intensity and over a moist forest floor. High-severity burns were of high-intensity and over a dry forest floor. Relative humidity and wind speed were similar for the two burn treatments, however, the fine fuel moisture and ambient temperature were quite different (Table 1).

Conditions for both fires fell within the guidelines established by the USDA-Forest Service, Southern Region. Andrew Pickens District guidelines are more conservative than the Region's, requiring 9 and 8 percent moisture content, respectively, of woody fuels 6-26 mm in diameter. Fuel moisture content met the Region's guidelines for the high-severity burns while the fuel moisture content for the low-severity burns surpassed both guidelines at 11 percent (Table 1).

Fuel loading, litter and duff layer thicknesses, and mineral soil exposure were measured along fifteen 15-meter transects, prior to burning. Starting points for the transects were randomly located, however, azimuths were varied to ensure sampling along several slope gradients. Pins were installed flush with the top of the duff layer to estimate forest floor consumption. Consumption was measured in millimeters from the top of the pin to the forest floor. Woody fuels, forest floor, and mineral soil were sampled immediately prior to ignition to determine moisture content. Post-burn transect measurements determined fuel load consumption and mineral soil exposure. Shortleaf pine seedlings were planted in the fall of 1991.

One 3 m x 10 m plot had been randomly located in each treatment area for a previous study of artificial rainfall (Robichaud and Waldrop 1994). One of these

plots was randomly selected from the four replicates of each burn treatment to monitor total runoff and sediment resulting from natural rainfall. Samples were collected in 55-gallon barrels fed by covered channel tubing, located at the base of the plot, that extended the width of the plot across the slope. Depth of runoff in barrels was measured after each rainfall event to determine volume.

Sediment in runoff was measured after adding 1000 ml of 0.2-N aluminum sulfate (Alum) to flocculate suspended solids. This solution was poured into beakers, oven-dried at 75 degrees C, and weighed to determine concentrated sediment. A 1,000 ml runoff sample was collected to determine phosphorous (P) and potassium (K) concentration that was measured by the Clemson University Agricultural Chemical Services Department.

Runoff and sediment production were measured after each rainfall event, from September 1991 through September 1992. A portable weather station recorded rainfall intensity and duration on a data logger, downloaded after each rainfall. This information was used to help correlate rainfall and erosion.

Vegetative response was measured at the end of the first full growing season after burning (September 1992). Within each treatment area, one 0.2 ha plot was randomly located to measure survival and height growth for planted pines. Two vegetation plots, measuring 0.01 ha each and randomly located within each treatment area, were used to measure height growth of hardwoods and naturally-regenerated pines. Hardwood stumps were mapped and inventoried for species identification, number of sprouts, height of dominant sprout, and crown diameter. A 0.004 ha plot was established in the center of each 0.01 ha

vegetation plot for an inventory of all regenerated woody stems—sprouts and seedlings.

Plant biomass was sampled in four 0.25 m x 4.0 m plots, located at all corners of each 0.01 ha vegetation plot (a total of 8 biomass plots per treatment area). All vegetation within these small plots was clipped at ground level and separated into categories: forbs, grasses, vines, shrubs, and trees. Samples were oven-dried at 80 degrees C for 48 hours, weighed, and ground with a Wylie mill using a 2-mm screen. Nutrient concentration was measured by the Clemson University Agricultural Chemical Services Department.

RESULTS AND DISCUSSION

Prior to ignition, ambient temperature and forest floor moisture content differed significantly between treatments. The low-severity burns occurred at midday when ambient temperature had not yet peaked, while high-severity burns occurred in the afternoon when the sun was most intense (Table 1). Litter, duff, and soil moistures prior to low-severity burns were significantly higher than those prior to the high-severity burns (Table 1). The greatest difference occurred in moisture content of the litter layer which contained 65.2 and 5.2 percent for low- and high-severity burns, respectively.

The two burn treatments resulted in widely differing forest floor conditions. Low-severity burns consumed 73 percent of the litter layer and 30 percent of the duff layer. The low-severity areas had a blackened, charred appearance after burning, indicating partial to minimal forest floor consumption. The forest floor was 63 mm thick and mineral soil was exposed on less than 1 percent of the area. Less than half of the fine woody fuels (< 6 mm) was consumed.

In contrast, high-severity burns consumed 96 percent of the litter layer and 76 percent of the duff layer. After burning, high-severity areas had an ashy-white and brown appearance, indicating near total consumption of forest floor and visible exposure of mineral soil. These areas had a thin forest floor (11 mm) and mineral soil exposure on 47 percent of the area (Table 2). Virtually all fine fuels (< 6 mm) were consumed.

During the year after burning, 31 rainfall events occurred. Although total rainfall for the year was very similar for both treatments, sediment lost from the low-severity site was less than sediment lost from the high-severity site (Table 3). The sediment yield and percent rainfall lost as runoff are shown (Figures 1 and 2, respectively) for major rainfall events (> 25mm). Remarkably, infiltration rates remained high for both areas as shown by the small percentage of rainfall lost as runoff (Table 3 and Figure 2).

Three major storms accounted for 29 and 69 percent of annual sediment production from the low- and high-severity treatments, respectively (Figure 1). A storm on

22 July reached a 5-minute maximum intensity of 176.6 mm/hr (Figure 3). Sediment production from this storm was 2080.6 kg/ha on the high-severity site, 15 times the sediment loss on the low-severity site for the entire year.

Table 2—Pre- and post-burn forest floor characteristics for low- and high-severity burns

	Low severity	High severity
Litter depth		
Pre-burn	78 mm	29 mm
Post-burn	10 mm	<1 mm
Duff depth		
Pre-burn	76 mm	42 mm
Post-burn	53 mm	10 mm
Soil exposure	<1%	47%

Table 3—Total runoff and sediment loss for one year after burning (Sept 1991 - Sept 1992) for low- and high-severity burns.

	Low severity	High severity
Rainfall (mm)	1,358	1,352
Runoff (mm)	16.9	79.2
Percent of rainfall	1.2	5.9
Sediment loss (t/ha)	0.14	5.75

Plant biomass production was twice as high for the low-severity treatment after one growing season, the largest difference shown in forbs and grasses (Table 4). The forest floor on low-severity sites acted like mulch, limiting surface evaporation. Tree biomass was greater on high-severity sites, but not statistically significant. All sampled trees were hardwood sprouts emerging from stumps having well-developed root systems and less dependency on forest floor coverage than grasses and forbs.

Soil samples indicated no significant differences in nutrient content between the two treatments. Total nitrogen, phosphorous, and potassium (N,P,K respectively) content in all plants collected from low-severity sites was greater than those from high-severity sites due to larger biomass production (Table 5). However, concentrations of N, P, and K were significantly higher on high-severity sites, suggesting that moisture limited plant growth rather than nutrient availability. Conversely, lower concentrations of nutrients in plants on the low-severity site, where infiltration and water retention was higher, suggest that nutrients were limited.

The lower planted pine survival rate on low-severity sites probably resulted from greater competition from herbaceous growth. Height growth of planted pines was unaffected by fire severity (Table 6).

Hardwood regeneration was significantly different between the two treatments. Number of hardwood stems was 1.8 times greater on high-severity sites than on the low-severity sites (Table 7). This difference is probably a result of a greater number of stems prior to harvest, because the number of sprouts per stump was not affected by the burning treatment.

Table 4—Biomass production one growing season after low- and high-severity burns

	Low severity	High severity
	(t/ha)	(t/ha)
Grasses	0.41a	0.08 b
Forbs	0.66a	0.22 b
Vines	0.08a	0.08a
Shrubs	0.13a	0.01 b
Trees	0.39a	0.43a
Total	1.67a	0.79 b

Means followed by the same letter within a row are not significantly different at the 0.05 level.

Table 5—Plant concentration and content of nitrogen, phosphorous, and potassium (N,P, and K, respectively) for low- and high-severity burns

	Concentration(%)		Content(kg/ha)	
	Low Severity	High Severity	Low Severity	High Severity
Grasses				
N	1.06a	1.26 b	534.7a	251.4 b
P	0.08a	0.10 b	65.9a	32.8 b
K	1.07a	1.25a	1,284.9a	437.2 b
Forbs				
N	0.81a	1.15 b	439.3a	104.8 b
P	0.10a	0.15 b	33.2a	8.3 b
K	1.95a	2.00a	443.4a	104.0 b
Trees				
N	1.02a	1.19 b	397.6a	513.0a
P	0.09a	0.10 b	35.1a	43.1a
K	0.50a	0.78 b	230.0a	336.2a
All Plants				
N	1.01a	1.20 b	1,535.4a	954.4 b
P	0.09a	0.12 b	150.6a	93.4 b
K	1.17a	1.24a	2,080.9a	939.6 b

Means followed by the same letter within a row are not significantly different at the 0.05 level.

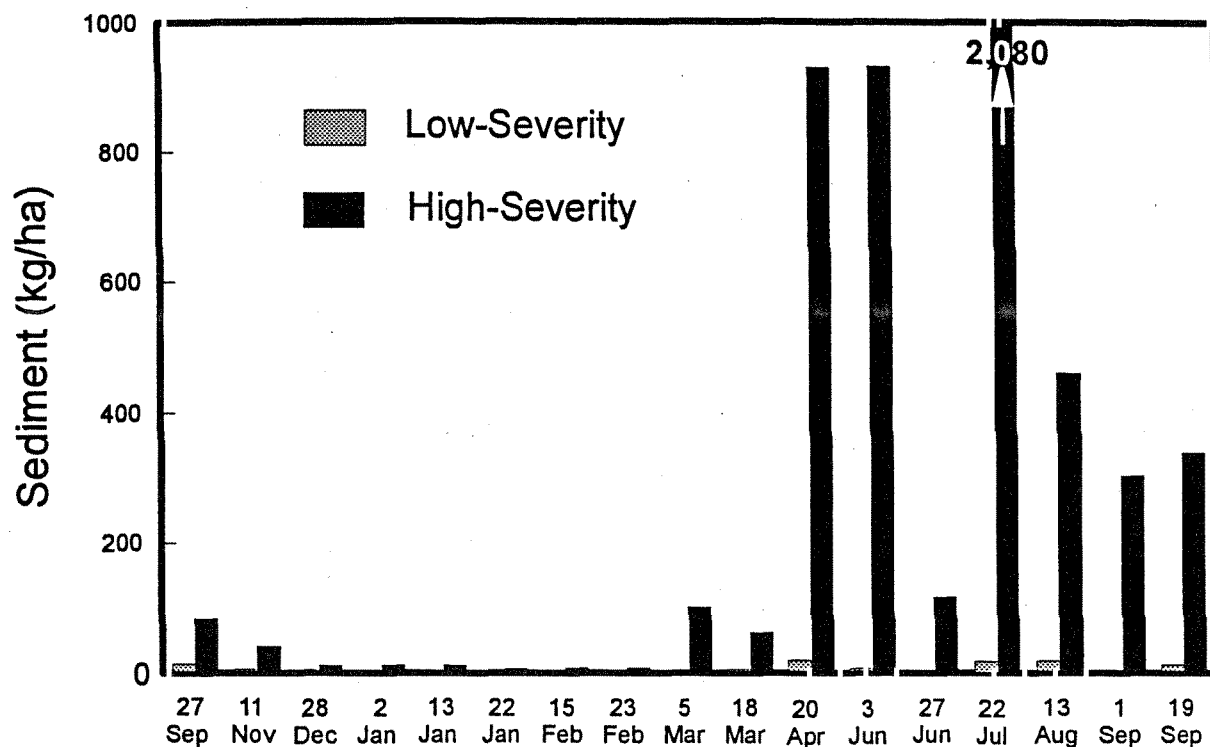


Figure 1—Sediment produced (kg/ha) during 17 major rainfall events (September 1991 - September 1992) for low- and high-severity burns

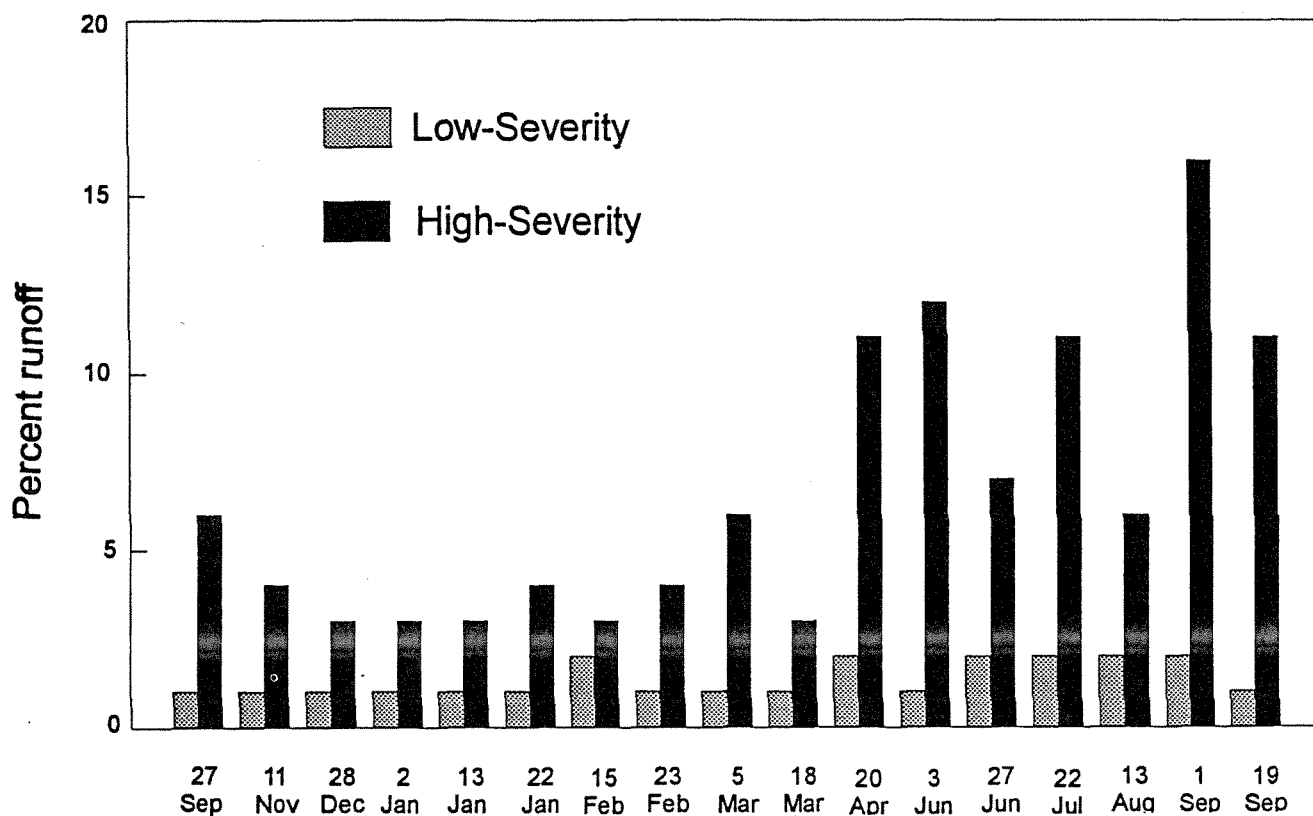


Figure 2—Percent rainfall lost as runoff on low- and high-severity burns for 17 major rainfall events (September 1991 - September 1992).

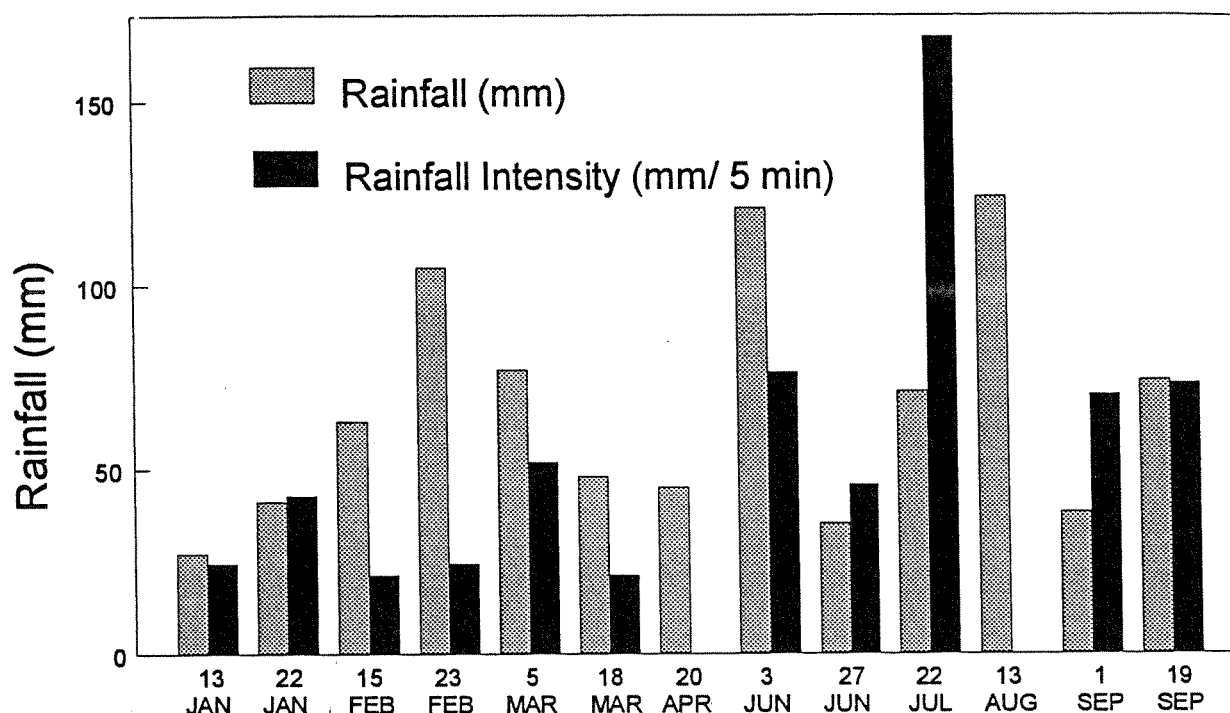


Figure 3—Rainfall and rainfall intensity for 13 major rainfall events (September 1991 - September 1992)

Table 6—Height growth and survival of planted pines

Fire severity	Height growth	Survival
	(cm)	(%)
High	27.9a	77a
Low	28.5a	58 b

Means followed by the same letter within a column are not significantly different at the 0.05 level

Table 7—Hardwood regeneration after one growing season for low- and high-severity burns

Fire Severity	Blackgum	Oak	Other Hardwoods	All species
Stems per hectare				
High severity	1,704a	2,124a	4,026a	8,744a
Low severity	1,803a	1,309a	1,630 b	4,965 b
Sprouts per stump				
High severity	7.1a	6.5a	10.2a	8.5a
Low severity	6.0a	7.3a	5.1 b	6.9a
Sprout height (m)				
High severity	1.0a	1.0a	0.9a	1.0a
Low severity	1.4 b	1.2 b	1.1a	1.2 b

Means followed by the same letter within a column are not significantly different at the 0.05 level

Height growth of hardwood sprouts was lower in high-severity burn areas compared to that on the low-severity burn areas (Table 7). Danielovich and others (1987) showed that the fell-and-burn technique significantly reduced the height growth of hardwood sprouts, because it shortened the growing season. Hardwood sprouts in burned treatment areas were significantly shorter than in unburned areas for all species and groups (Waldrop 1994). These findings suggest that spring felling of residuals and summer burning will significantly reduce hardwood sprout height-growth for at least the first growing season. Results also suggest that fire severity affects height-growth of hardwoods. However, these differences may result from the timing of the burns rather than their effect on growth rates.

CONCLUSIONS

This study suggests fire severity can have negative effects on runoff, sediment production, and site productivity. The high-severity treatment resulted in almost total consumption of litter and duff layers, excessive exposure of mineral soil, increased runoff, increased erosion, and lower biomass production. After high-severity burning, the thin residual forest floor decayed, exposing more mineral soil to erosion. Decay will probably continue until invading vegetation begins to rebuild the forest floor. Positive effects include increased pine survival rates and decreased hardwood sprout growth. By comparison, the low-severity treatment retained most of its forest floor, which

protected the site from erosion and runoff. This treatment also had greater biomass regeneration in addition to unburned slash, which formed debris dams reducing runoff and sediment movement. However, the survival of planted pines was reduced.

Long-term effects are still unknown. Planted pines on high-severity sites may lose vigor for several years, but may ultimately benefit from reduced competition. Since high-severity burns reduce overall short-term site productivity, they should probably be avoided. Burning prescriptions must be developed to protect the forest floor, and, therefore prevent erosion and other negative effects. Burning prescriptions in this study met regional standards for temperature and relative humidity, indicating the need for more site-specific standards. Litter and duff layer moisture content may be a more critical measure in protecting site quality than fuel moisture stick readings. Site-specific methods developed to prevent forest floor consumption based on weather and fuel conditions could reduce future losses in site and/or water quality.

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Eighty-eight papers and two abstracts address a range of issues affecting southern forests. Papers are grouped in several categories including a general session, ecosystem management, vegetation management, pest management, natural disturbance, biometrics, economics, site productivity, site impacts, ecophysiology, genetics, regeneration, silvicultural systems, stand development, and intermediate management. Fourteen papers, on varying topics, are presented from a poster session.

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